Lawrence Berkeley National Laboratory
High Tech Buildings Program

Cleanroom Benchmarking Project
Site Report

Facility A
Building 3

Fremont, CA

Sponsored By:

Pacific Gas and Electric Company
Market Transformation Program

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Oakland, CA 94607
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APPENDICES

I. EXECUTIVE SUMMARY

As part of PG&E's Cleanroom Benchmarking Project, energy use by the environmental systems of Facility A Building 3 was monitored for two weeks in June 2000. Building 3 contains 25,600 square feet of Class 10 cleanroom area and 10,800 square feet of Class 100 cleanroom area used in the production of hard disks. This site report reviews the data collected by the monitoring team and presents a set of performance metrics as well as a complete set of trended data points for the central plant and cleanroom air handling systems. Some of the most important metrics are summarized below in Table 1.

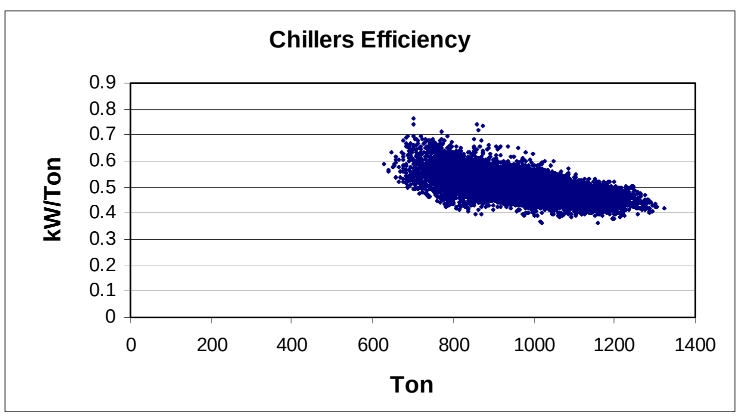
The pressurized plenum design and the bay-chase layout of the cleanrooms led to superior performance in the air handling systems. However, there are still several opportunities for energy efficiency improvements in the central plant area, which consumes more energy than all the fans combined. Some of the most promising opportunities include free cooling, utilization of all existing tower capacity, configuration of a medium temperature chiller for tools and sensible cooling in the cleanroom, and improving controls on the cooling towers. There are also several areas, such as the management of compressed air, with potential for energy efficiency improvement that would require further investigation.

Table 1. Summary of Important Metric Results for Facility A Building 3

Metric Name	Metric Value
Chiller Efficiency	0.505 kW/ton
Central Plant Efficiency	0.689 kW/ton
Class 10 Recirculation Fan CFM/kW	5460 CFM/kW
Class 100 Recirculation Fan CFM/kW	7845 CFM/kW
Annual Energy Cost per Square Foot of Cleanroom	$57.91

The metrics indicate that Facility A has a very efficient chiller and a high performing central plant overall. The recirculation fans in both cleanrooms are operating at a very high level of efficiency. The low velocity air handlers as well as the low pressure drop of the pressurized plenum with a raised floor and chase return design contribute to this excellent performance. The Class 100 fan system operates at a lower air velocity than the Class 10 fans, contributing to its higher level of energy efficiency.

Because the chillers, pumps, and towers face varying loads, the performance metrics for these major components were monitored at a frequency of one minute and plotted to create a set of kW/ton vs. ton graphs. (See Appendix B.) The chillers and pumps are performing remarkably well. The cooling tower metric plot reflects a motor control settings problem that should be investigated further.



These metrics will have additional value when Facility A compares its performance to other cleanroom owners, and especially, when it undertakes energy efficiency retrofit projects in the future to improve the performance of its cooling towers and process utilities.

II. INTRODUCTION

The Cleanroom Benchmarking project aims to establish energy metrics with which cleanroom owners can evaluate their energy efficiency performance and identify opportunities for improvements that reduce their overall operating costs. It is administered by PG&E and funded through the California Institute for Energy Efficiency. The Facility A Site Plan presented to the Facility Manager May 31, 2000 includes the site monitoring plan carried out in order to collect the data presented in this Site Report. (See Appendix H.) The General Plan for the Cleanroom Benchmarking Project, also presented on May 31, 2000, provides additional information on the program.

With this report, Facility A is receiving the energy monitoring data collected at its facility over the period of 17 days as a service provided by PG&E to participants in the Cleanroom Benchmarking Project. This Site Report summarizes the data collected and presents the key energy performance metrics with which Facility A can compare its operations with other cleanroom facilities. First, the report reviews site characteristics, noting design features of the central plant and the cleanrooms monitored. Second, the energy use for the building, central plant, and cleanrooms is broken down to major components. Third, performance metrics tracked through the Cleanroom Benchmarking Project are presented for the Facility A Building 3 site. Finally, key energy efficiency opportunities for Facility A's facility will be noted. The data collected, methodology documentation, and additional energy efficiency observations are included among the nine appendices.

III. REVIEW OF SITE CHARACTERISTICS

A. Campus

Facility A is a hard disk manufacturer located on a campus of four buildings in Fremont, California. The total square footage for the campus is 234,010 as reported by the company. There is one PG&E meter serving Buildings 1, 2 and 3. Facility A leases space from the separate owner of Building 4, which has a separate meter under a different PG&E client name. Natural gas is supplied with a dedicated meter for each building, and Facility A pays PG&E for gas transport as well as Enron for gas supply.

B. Building 3 Facility

Facility A Building 3 was the facility monitored in the cleanroom benchmarking process. This 124,010 square foot (sf) building was constructed over the course of five months in 1996, with hard disk production beginning in early 1997.

The building contains 10,430 sf of Class 100 area and 25,600 sf of Class 10 area, which are considered Primary Cleanroom Areas for data reporting purposes. The cleanrooms are designed with a bay-chase layout using four bays. (See Appendix G.) The chase areas, which are considered Secondary Cleanroom Area, account for 26,600 sf of building area. Two floors of office space surround the cleanroom space in the center of the building. Because the cleanroom process and fan loads are very stable, the ±15% daily swing in cooling tonnage (see Appendix B) is largely attributed to the office loads.

Currently, three of four bays are operational in the Class 10 area, and 3.5 of four bays are operational in the Class 100 area. Facility A will expand into the Bay 4 area as its production demand increases.

The Building 3 central plant incorporates primary and secondary chilled water loops served by two 800 ton centrifugal chillers. During the monitoring period, the chillers peaked at 1323 tons with an average load of 968 tons. (See Appendix A.) Secondary chilled water is delivered directly to the make up air handling units and office air handling units as well as to the heat exchanger that serves the process cooling water loop. The secondary chilled water loop has a fairly high ΔT, resulting in a low pumping load. A tertiary chilled water loop is drawn from the secondary to serve the recirculation air handling units and a collection of process utilities. (See Appendix G.) There is a set of pumps for each chilled water loop as well as the condenser water loop serving the chiller and cooling towers.

800 Ton Centrifugal Chiller, Facility A

Baltimore Air Coil Cooling Towers

As noted in section VI of this report, the tower control settings are causing excessive motor cycling, and as a result, the condenser water supply temperature to the chiller is also swinging 10°F approximately every 10 minutes. Despite this challenging operating condition, the chillers are remarkably effective at maintaining chilled water supply temperature. (See Appendix A.)

The tertiary pumps are vastly oversized for the actual sensible cooling load met by the recirculation air handlers. This is likely the result of overly conservative estimates for cleanroom heat load as calculated by the designer. Although it is not uncommon for tool power demand to be overstated by manufacturers and then increased by a safety factor by the HVAC designers, Facility A's Building 3 tertiary loop includes 200 hp of installed pump motor equipment (excluding 100 hp back up) to serve an actual load of approximately 25 hp.

The hot water plant consists of a boiler and a primary-secondary hot water loop providing reheat to the make up air handlers and the office air handlers. The pump size and design flow for this system is very small compared to the chilled water system, with a flow rate of less than 5% the primary chilled water flow.

The Building 3 central plant is designed with N+1 redundancy, so in addition to the number of pumps, towers, chillers, and compressors required to serve the expected building loads, there is one additional backup piece of equipment.

Boiler Plant, Facility A

DI Water Plant, Facility A Building 3

The utilities provided by the central plant include compressed air, nitrogen, deionized (DI) water, process vacuum, and house vacuum. The compressed air and DI water plant represent major loads with potential for efficiency improvements. However, the energy consumption of these utilities in the environmental systems is difficult to benchmark between facilities because their use is heavily dependent on the cleanroom processes. Therefore, these utilities were a low priority for data collection.

Energy consumption for Building 3 does not depend significantly on either weather conditions or production level. The monitoring carried out by Supersymmetry was conducted during the warmest weeks of the year from June 12 to June 29, 2000. Although the average ambient conditions were 73.4°F and 58.4% relative humidity, the dry bulb temperature ranged from 65°F to 105°F during that time, and yet the building power demand was very stable. During the monitoring period, production rates in the Building 3 cleanrooms ranged widely based on end of shift reports, also having little discernable impact on energy consumption with the exception of June 16, 2000. (See Appendix B, Building Conditions.) In order to maintain indoor building conditions and keep process equipment on standby, Building 3 carries a nearly constant load of 3500 kW – *independent* of the production rate or the outside weather conditions.

C. Class 10 Cleanroom Design

Both the Class 10 cleanroom and the Class 100 cleanroom have a highly efficient pressurized plenum design. (See Appendix G for a schematic elevation drawing.) The bay-chase design allows a large volume of air to travel at low velocity through an open chase-return space with minimal pressure drop.

Make up air provides less than 1% of the total recirculated air in the cleanroom, a result of the low ventilation requirements in the large ballroom area with a high recirculation rate and low exhaust requirements. This low proportion of make up air reduces to a negligible level the impact of outside conditions on the energy consumption required to maintain cleanroom conditions. Supply air from two make up air handlers per bay is ducted to each recirculation unit, which serve two plenum boxes each. The HEPA ceiling coverage is 100%.

Make Up Air Handler #2

The recirculation units maintain a constant pressure in the 18” tall plenum boxes in order to deliver air through the 99.999% HEPA filters at a ceiling velocity of approximately 90 fpm. The Facility A Contamination Control Team carefully tracks ceiling velocity, and the range of 80-100 fpm has yielded reliable production results. When the ceiling air velocity was reduced below 80 fpm during a trial period in 1999, production reportedly dipped, so the 90 fpm ceiling air velocity target was restored.

A 3-foot raised, grated floor provides the return air passage for the room. The space beneath the raised floor is shared with equipment conduit, pipes, and large bundles of cable, but the space is large enough to provide minimal obstruction to the air flow. The air is then recirculated up through a grated floor in the chase area and drawn into the 25 sf recirculation unit intake filters near the ceiling.

There are 32 recirculation units per bay and 30 recirculation units serving small Class 10 cleanroom areas across the main corridor from the ballroom area. (See Appendix G.) The air flow schematic for the Class 10 cleanroom does not include any general exhaust. Due to the static pressure differential maintained between the Class 10 and Class 100 cleanrooms, the air flow cascades from the Class 10 area to the Class 100 area through the common return space that they share. Air is also effectively exhausted from the Class 10 area through exfiltration, which was not explicitly measured. The cleanroom itself has a tight design, though there is significant leakage from the return air spaces.

During the monitoring period, the Class 10 cleanroom operated within its 68°F ±2°F temperature conditions, though the relative humidity in the room was consistently measured on the high side of its 50% ±5% range, averaging 54% RH.

D. Class 100 Cleanroom Design

The design of the Class 100 cleanroom area is virtually the same as the Class 10 with a few notable exceptions. The HEPA coverage is 25%. There are only 6 recirculation units per bay instead of 32, and there is only one make up air handler per bay instead of two. The Facility A Contamination Control team does not regularly monitor ceiling air velocity in the Class 100, and therefore, the measured ceiling velocity is less consistent, averaging 103 fpm. There is no raised floor return space in the Class 100 area, so 24" tall side-wall return areas provide an outlet to the chases.

The process in the Class 100 area requires general exhaust of about 7200 CFM, with the remainder of the exhaust leaving the space through exfiltration. There are no processes in either the Class 10 or Class 100 area that require scrubbed or solvent exhaust. Process engineering design decisions, therefore, had a significant impact on the cleanroom energy use because, in addition to reducing the exhaust load, the process design reduced the overall make up air requirement and eliminated the need for scrubber or neutralization systems, which would require additional energy input.

During the monitoring period, the Class 100 cleanroom operated consistantly at a measured temperature on the high end its specified range of 68°F ±2°F, and also maintained a relative humidity level above 50%, though within the control specifications. Table 2 profiles the major air handling performance parameters for both cleanrooms.

Table 2. Measured Air Handling Parameters for Class 10 and Class 100 Cleanroom Areas

Description	*Class 10 Cleanroom*		*Class 100 Cleanroom*	
Primary Area	25,600	sf	10,400	sf
Total Make-Up Air	17,700	CFM	9,600	CFM
Total Make-Up Fan Power	15	kW	6.4	kW
Total Recirculation Air	1,900,000	CFM	227,500	CFM
Total Recirculation Fan Power	348	kW	29	kW
Room Air Changes per Hour	445	ACH	105	ACH
Total Exhaust Air	--	CFM	7200	CFM
HEPA Filter Efficiency	99.999	%	99.999	%
HEPA Filter Ceiling Coverage	100	%	25	%
Ceiling Filter Velocity	87	fpm	103	fpm

IV. SITE ENERGY USE CHARACTERISTICS

A. Site Energy Use

Facility A pays over $2.5 million annually in energy costs at its Fremont, California campus. Over 75% of this operating expenditure can be attributed to Building 3. The campus has a fairly consistent electricity demand and a flat load shape due to its constant cleanroom operation. (See Appendix E.) Tables 4 and 4 outline the electricity and gas costs for the Facility A Campus as compared to Building 3 alone.

Table 3. Annual Energy Use Data

Meter Level	Annual Electricity Usage (MWh/yr)	Annual Electricity Cost ($/yr)	Annual Natural Gas Usage (Therms/yr)	Annual Natural Gas Cost ($/yr)	Annual Total Cost ($/yr)
Campus	38,000	$2,530,000	334,000	$258,000	$2,780,000
Building 3	30,000	$2,010,000	131,000	$97,000	$2,107,000

Source: Facility data provided by PG&E bills May 1999 to April 2000. Building 3 values determined by applying equivalent electricity costs to on-site submeter data from January 1999 to December 1999. The Campus figures include only Buildings 1, 2, and 3. Energy costs are calculated at an average resource price of $0.065/kWh and $0.75/Therm, which reflect the average of $0.067/kWh and $0.73/Therm Facility A pays on its monthly bills.

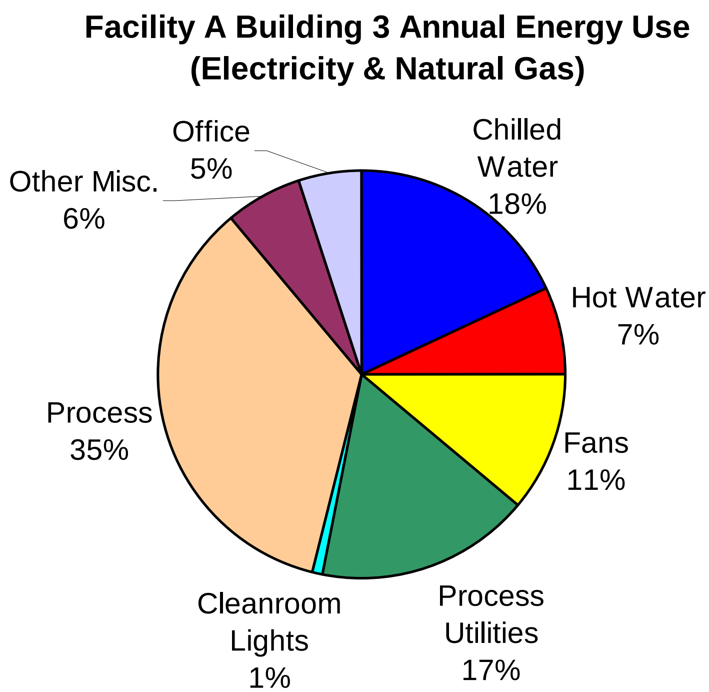
Table 4. Annual EUI and Energy Cost per Square Foot

Meter Level	Area (sf)	Energy Utilization Intensity (kWh/sf)	Annual Energy Cost per Building Square Foot ($/sf)
Campus	234,010	204	$11.88
Building 3	124,010	273	$17.00

Energy from natural gas has been converted to kWh for the EUI calculation.

B. Building 3 Energy Use

The Building 3 energy use reported in Table 3 above can be disaggregated into the main components of the building energy systems: heating, cooling, air handling, and production. The cleanroom environmental systems of Building 3, including the process utilities, account for 55% of the total annual energy use for the building. Process tools account for over one third of the total power, and office loads along with other miscellaneous loads account for the remaining 11%.



C. Central Plant Energy Use

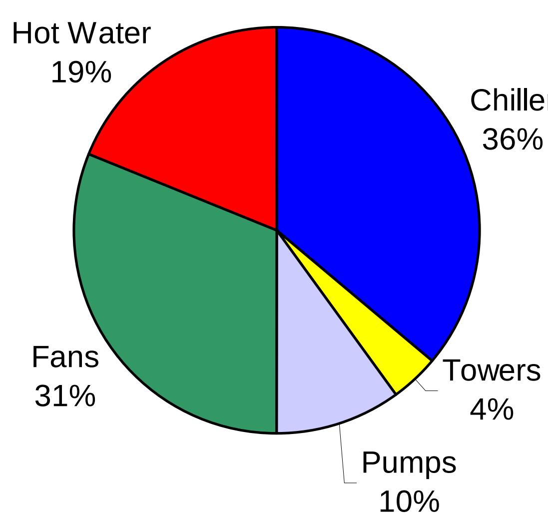
Table 5. Central Plant Energy Use by Major Components

Description	Average Load (kW, Therms)	Average Efficiency	Annual Hours of Operation	Electricity (MWh/yr)*	Total Natural Gas* (Therms/yr)	Total Cost ($/yr)**
COOLING						
Chillers	486	0.505 kW/ton	8760	4,260		$277,000
Pumps	135	0.142 kW/ton	8760	1,180		$76,900
Condenser Water Pump	40	0.042 kW/ton	8760	350		$22,750
Towers	45	0.046 kW/ton	8760	394		$25,600
HEATING						
Boiler (Therms)	13.7		8760	120	11,300	$271,000
Pumps (kW)	4.0		8760	35		$2,280
PROCESS UTILITIES						
Compressed Air	196		8760	1720		$112,000
DI Water	33	0.094 kW/gpm	8760	289		$18,800
Other Utilities						
TOTAL	900			7,998		$783,600

* *Simple annualization based on one week of data. Methodology explanation in appendix.*

** *For the purposes of benchmarking comparisons, cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh ($65/MWh) and $0.75/Therm.*

Annual Energy Use of HVAC Equipment (Electricity & Natural Gas)



D. Class 10 Cleanroom Energy Use

The energy consumption attributed to the cleanroom air handling system, process tools, and lighting are reported for the Class 10 and Class 100 cleanrooms in Table 6 and Table 7, respectively. This breakdown of energy use by equipment helps identify major loads and related costs. The operation of the process tools dominate the energy consumption inside the cleanroom, but the fans also contribute significantly to the heat load.

The process tools have a high standby load as noted in Section III, Part B, so even when the production line is idle, the total process load does not drop significantly. As detailed in the Data Collection Notes (Appendix C), the process loads quoted in this report are a pro-rated figure based on the relative square footage of the Class 10 area to the Class 100 area since they both serve the same production lines. The Class 10 cleanroom area is not served by exhaust fans.

Table 6. Class 10 Cleanroom Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)*	Total Cost ($/yr)**
AIR HANDLING					
Makeup Fans	15	1,180	8760	131	$8,500
Recirculation Fans	348	5,460	8760	3,050	$198,000
Exhaust Fans					
PROCESS	1040		8760	9,110	$592,200
LIGHTS	46.1		8760	404	$26,200
TOTAL	1450			12,700	$824,900

* *Simple annualization based on one week of data. Methodology explanation in appendix.*

** *Cost of electricity assumed to be constant (without time of day or demand rate structure): $0.065/kWh.*

E. Class 100 Cleanroom Energy Use

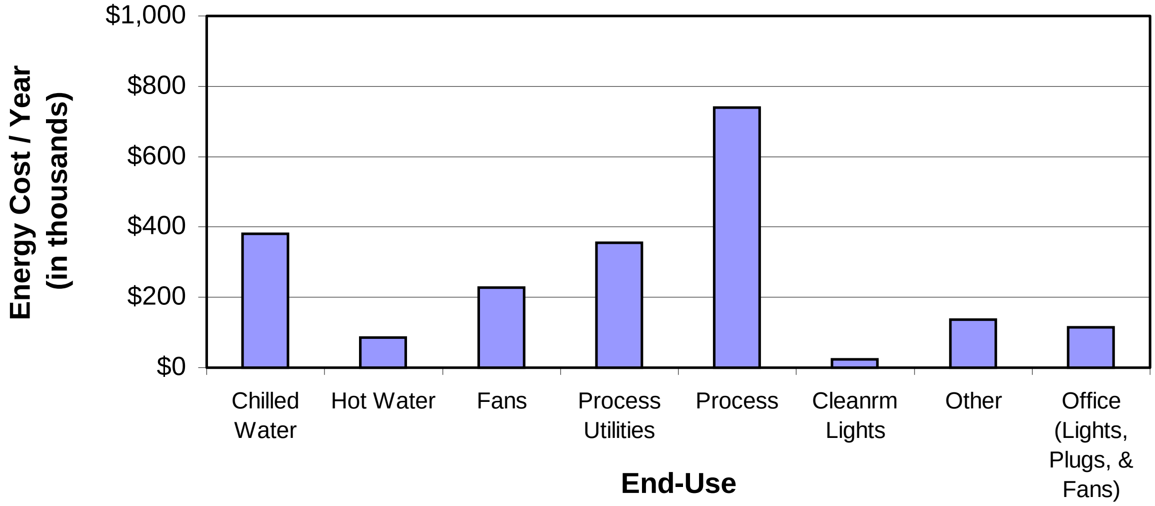
Table 7. Class 100 Cleanroom Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)*	Total Cost ($/yr)**
AIR HANDLING					
Makeup Fans	6.4	1,500	8760	56.1	$3,640
Recirculation Fans	25.6	7,845	8760	224	$14,600
Exhaust Fans	4.5	1,600	8760	39.4	$2,560
PROCESS	260		8760	2,280	$148,200
LIGHTS	19.4		8760	177	$11,500
TOTAL	316			2,780	$180,500

* *Simple annualization based on one week of data. Methodology explanation in appendix.*

** *Cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh.*

F. Annual Building 3 Energy Costs Bar Chart



The bar chart above illustrates the relative cost of supporting the major energy end-uses in Building 3. While the process power may be a non-negotiable point of energy consumption, its associated heat load requires a large HVAC system that can be optimized without interfering with the cleanroom conditions. Therefore, investments in energy efficiency to reduce operating costs should be made in the operation of the fans and the chilled water plant.

V. SYSTEM PERFORMANCE METRICS

Metrics are ratios of important performance parameters that can characterize the effectiveness of a system or component. In order to gage the efficiency of the entire building system design and operation, the Cleanroom Benchmarking Project tracks 35 key metrics at four different system levels – energy consumption, central plant, process utilities, and cleanroom.

Annual Resource Use

As indicated in the report figures, nearly 90% of the total building power demand can be attributed to the cleanroom operation in Building 3. Therefore, the annual energy cost per square foot is the sum of the total electricity and gas cost attributed to the building and the 36,400 sf of primary cleanroom square foot area in the 124,010 sf building.

Description	***Metric***	
Annual Energy Cost *per Cleanroom Square Foot*	$57.91	/sf
Annual Fuel Usage	3.6	Therms/sf/yr
Annual Electricity Usage	824	kWh/sf/yr
Annual Energy Usage	2.85	MBtu/sf/yr
Annual Peak Demand	104	W/sf
Average Power Demand	94	W/sf
Load Factor	0.90	

Based on Building 3 energy consumption and 36,400 sf of primary cleanroom square footage.

Central Plant

Metrics of kW/ton are based on the total average equipment power for the chilled water plant and the average operating tonnage of the total chilled water plant. These figures are useful for making comparisons between facilities, but more substantial information is expressed in the metric plots in Appendix B that reflect kW/ton performance at a sampling frequency of one minute over the course of a week.

Description	*Metric*
Chiller Efficiency	0.502 kW/ton
Tower Efficiency	0.046 kW/ton
Condenser Water Pumps Efficiency	0.042 kW/ton
Chilled Water Pumps Efficiency	0.098 kW/ton
Total Chilled Water Plant Efficiency	0.689 kW/ton
Cooling Load Density	128 sf/ton

Cooling Load Density is based on the total square foot area served by the facility central plant, which is the entire area of Building 3, and the average tonnage of the central plant.

Process Utilities

The following metrics for process utilities can also be used for benchmarking cleanroom performance. The measurements required to calculate these metrics were low in the priority list established in the Facility A Site Plan (see Appendix H), and the data collected during the monitoring period according to that prioritization did not include figures reflecting these areas of performance. The compressed air and DI Plant metrics could be especially helpful in assessing the benefits of any future modifications to these heavily used utilities.

Description	*Metric*
DI Plant Efficiency	kW/gpm
Compressed Air	BHP/100 ACFM
Nitrogen Plant Efficiency	CFM/kW
House Vacuum Efficiency	CFM/kW

Class 10 Cleanroom & Class 100 Cleanroom

Both the Class 100 and Class 10 cleanrooms yield superior performance in air handling efficiency due to the nature of the pressurized plenum design and cascading room pressurization. The Class 100 cleanroom is served by air handlers larger than those in the Class 10 area, which also supply air to larger pressurized plenum boxes than in the Class 10 area. The larger air handlers and lower air volume combine to yield a higher efficiency in the air handling system. The recirculation air handlers have a notably high CFM/kW efficiency ratio while the make up air handlers are performing at expected levels.

Although there is no active exhaust in the Class 10 cleanroom, exhaust fans in the Class 100 areas serve a specific tool in the production lines. The remainder of the exhaust air leaves the room via exfiltration from the return air chase area.

For Facility A, the cleanroom components operate at a constant level throughout the year. Therefore, these metrics are based on spot measurements without trended metric plots. All of the metrics involving area are based on the primary cleanroom area, which is the area that passes certification for Class 10 (25,600 sf) and Class 100 (10,400 sf). Process Tools Power Density is an exception because it is based on both the primary and secondary cleanroom area over which the tools are located. Though the Process Tools Power Density metric for Facility A is within an expected range for cleanroom design, it is worth noting that the tools alone account for a cleanroom energy intensity over 20 times that of commercial office space.

Description	***Class 10 Cleanroom Metric***		***Class 100 Cleanroom Metric***	
Recirculation Air Handler Efficiency	5460	CFM/kW	7845	CFM/kW
MUAH Efficiency	1180	CFM/kW	1500	CFM/kW
Make up Air CFM/sf	0.69	CFM/sf	0.89	CFM/sf
Recirculation Air CFM/sf	74	CFM/sf	21	CFM/sf
Recirculation Air ACH/hr	445	ACH/hr	105	ACH/hr
Exhaust System Efficiency	--	CFM/kW	1600	CFM/kW
Exhaust Air CFM/sf	--	CFM/sf	0.69	CFM/sf
Lighting Power Density	1.8	W/sf	1.94	W/sf
Process Tools Power Density	20.5	W/sf	20.5	W/sf
Primary Cleanroom to Total Building Area	0.206	ratio	0.084	ratio

VI. KEY SITE OBSERVATIONS REGARDING ENERGY EFFICIENCY

There appear to be a number of potential areas for energy savings in Facility A Building 3. Three of the most attractive are free cooling, configuration of a medium temperature chiller for sensible and process cooling in the cleanroom, and utilization of all existing tower capacity. This section includes a general description of the some of the most significant opportunities observed by the monitoring team. *Additional detail is included in Appendix I.* Improving energy efficient operations in the central plant will be strategically important in maintaining N+1 redundancy in Facility A Building 3 when the Bay 4 expansion is complete and the facility is running at maximum production.

Free Cooling

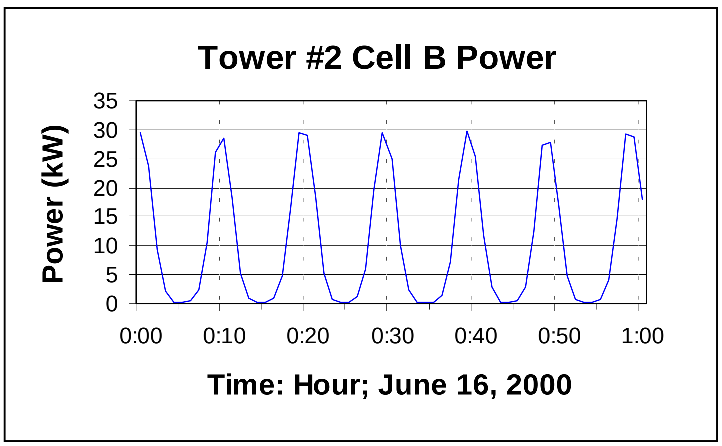
There is little question *if* free cooling would reduce electricity consumption, only *how much* it would save, and what its payback period would be. Free cooling utilizes the evaporative cooling capacity of a cooling tower to indirectly produce chilled water appropriate for use in the medium temperature loops, such as the process cooling and sensible cooling loops with supply temperatures above 55°F. Both the tertiary chilled water loop and the process cooling loops run at 58°F, which indicates a strong opportunity for free cooling. An evaluation of hourly weather data for the plant location combined with the information on the plant cooling load in this report can help predict the amount of free cooling available.

Medium Temperature Loop

A large amount of the cooling load at Facility A is served by a medium temperature loop, currently provided by flat plate heat exchangers. Chillers run more efficiently when producing higher temperature water, about 1.5% for every degree the chilled water temperature is increased. A medium temperature chiller loop would bypass the heat exchangers currently used to supply process cooling water and sensible cooling water from the lower temperature, inherently lower efficiency loop. The medium temperature loop would reduce the load on the low temperature loop significantly. Proper design and the retention of the existing heat exchangers could address redundancy concerns across the temperature loops.

Cooling Tower Control and Dispatch

The cooling tower fans at Facility A are cycling excessively. The constant ramping up and down of the fan speed reduces efficiency and could accelerate wear on the equipment. The controls should be tuned to dampen the cycling and ensure that the fans operate consistantly at a lower average speed. By dampening the cycling, the fan energy will be reduced. The fan energy is related to the cube of the fan speed, so eliminating the high speed peaks will result in a net energy savings.



Additional savings from the condenser system might be realized by leveraging the redundant tower capacity. By running all towers in parallel at a much reduced fan speed, the average velocity through the towers would be reduced resulting in a cube reduction in fan energy. To ensure maximum savings, the pumping system would need to be evaluated, the tower minimum flow determined and the condenser water temperature setpoint lowered (and ideally placed under some type of wetbulb-approach based control). The existing VFD control of the fans and common condenser headers and pumps make the Facility A site a promising candidate for this type of optimization.